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*Report of Survey Conducted at*

**U. S. ARMY COMBAT SYSTEMS TEST ACTIVITY**

ABERDEEN, MD

*August 1994*

## ***BEST MANUFACTURING PRACTICES***



*Center of Excellence for Best Manufacturing Practices*

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# PREFACE

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During the week of August 23, 1994, a Best Manufacturing Practices (BMP) survey was conducted at the U.S. Army Combat Systems Test Activity (CSTA), located at Aberdeen Proving Ground in Maryland. CSTA provides testing of field artillery, weapons, and ammunition and encompasses state-of-the-art facilities and equipment, advanced instrumentation, and comprehensive support capabilities to test a wide range of military weapons systems, equipment, and materiel. Located on 52,000 acres, capabilities are sustained by scientists, engineers, mathematicians, technicians, and support employees, totaling 1200 military and civilian personnel. These capabilities include the ability to design, develop, and construct state-of-the-art instrumentation incorporating the advanced technologies necessary to keep pace with testing requirements of current military systems.

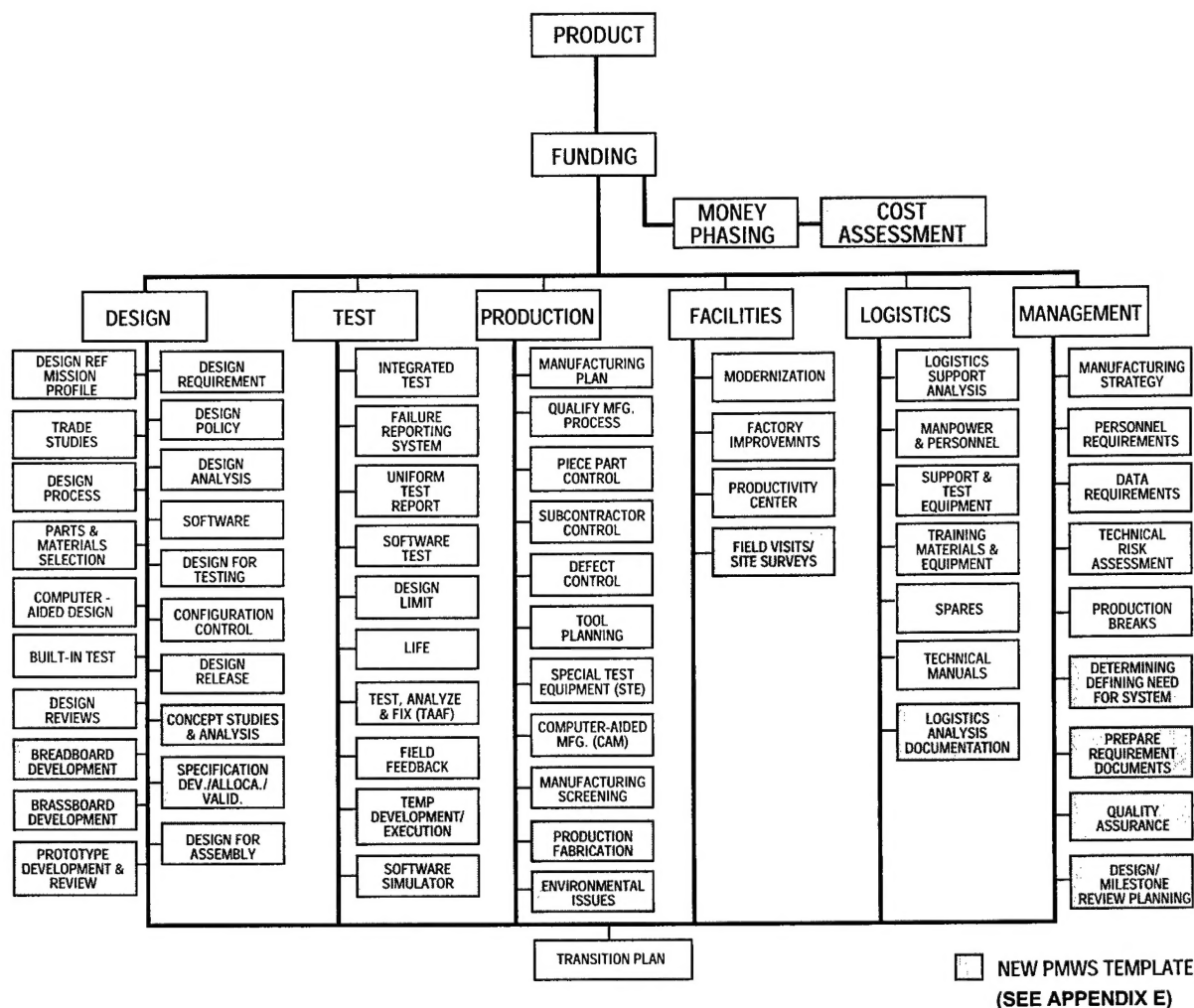
CSTA's impressive capabilities are enhanced by a strong, dedicated workforce that is constantly striving to expand its capabilities and improve customer relations. Communication is continuously stressed, as customer service is a critical element to CSTA's success. These elements of and emphasis on customer satisfaction and service set CSTA apart. With defense dollars continually at risk of reduction, CSTA's unique facility survives by ensuring that military *and* civilian customers are satisfied with testing capabilities and support. This concerted effort on CSTA's part led to its reception of the U.S. Senate Productivity Award for Maryland in the Service Category.

BMP surveys are conducted to identify best practices in one of the critical path templates of DoD 4245-7M, "Transition from Development to Production." This document provides the basis for BMP surveys that concentrate on areas of design, test, production, facilities, logistics, and management. Practices in these areas and other areas of interest are presented, discussed, reviewed, and documented by a team of government engineers who are invited by the company to evaluate the company's policies, practices, and strategies. Only non-proprietary practices selected by the company are reviewed. In addition to the company's best practices, the BMP survey team also reviews potential industry-wide problems that can be referred to one of the Navy's Manufacturing Technology Centers of Excellence. The results of the BMP surveys are entered into a database for dissemination through a central computer network. The actual exchange of detailed data is between companies at their discretion.

The Best Manufacturing Practices program is committed to strengthening the U.S. industrial base. Improving the use of existing technology, promoting the introduction of enhanced technologies, and providing a non-competitive means to address common problems are critical elements in achieving that goal. This report on CSTA will provide you with information you can use for benchmarking and is part of the national technology transfer effort to enhance the competitiveness of the U.S. Industrial Base.



## “CRITICAL PATH TEMPLATES FOR TRANSITION FROM DEVELOPMENT TO PRODUCTION”



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# SECTION 1

## EXECUTIVE SUMMARY

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### 1.1 ACTIVITY OVERVIEW

The U.S. Army Combat Systems Test Activity (CSTA), located at Aberdeen Proving Ground in Maryland, provides a premier range and test facility for the Department of Defense. Chartered in 1917 to provide testing of field artillery, weapons, and ammunition, CSTA now operates under the Army's Test and Evaluation Command (TECOM) and has become a world class, all purpose testing center. CSTA encompasses state-of-the-art facilities and equipment, advanced instrumentation, and comprehensive support capabilities to test a wide range of military weapons systems, equipment, and material. Testing covers the full range of life cycle support from concept evaluation and research prototypes through advanced development to quality assurance testing of production items. Testing is primarily performed for the Army, Navy, Air Force, and Marines, but CSTA also offers its services to other government agencies and private industry as well.

Capabilities at CSTA are sustained by scientists, engineers, mathematicians, technicians, and support employees, totaling 1000 military and civilian personnel. These capabilities include the ability to design, develop, and construct state-of-the-art instrumentation incorporating advanced technologies necessary to keep pace with testing requirements of current military systems. Soldiers from the field participate as members of test teams, bringing valuable field experience and training to the test effort. Located on 52,000 acres, CSTA maintains numerous exterior and interior firing ranges, automotive courses, environmental chambers that simulate temperature conditions, underwater explosive test ponds, nondestructive test facilities, and an extensive industrial complex to support equipment maintenance and experimental fabrication. These capabilities are used in the three principal directorates for technical management including Live Fire Vulnerability, Automotive and Support Equipment, and Armament and Ammunition Testing.

CSTA's impressive capabilities are enhanced by a strong, dedicated workforce that is not content with just being a government test facility with unique capabilities. It has actively sought to expand its capabilities and improve customer relations, satisfaction, and productivity over the last few years. This effort is initiated with a basic Test Performance Rating Questionnaire mailed to each customer at the completion of the test or with the final test report if one is

produced. This simple approach provides CSTA with important information and is used to guide actions to ensure that the customer is satisfied with performance and value.

An expanded marketing program has helped with the development of capability briefings, publishing new brochures, and provision of customer awareness training for the test directors who have the greatest contact with CSTA customers. New customers from other services have been secured, and an Office of Research and Technology Applications has been established to address technology transfer areas and to enter into creative partnerships. The successful marketing effort is reflected in the \$51 million dollars customers have invested in CSTA facilities since the program began.

Communication is continuously stressed, as customer service is a critical element to CSTA's success. Issues with customers can be directly addressed by a team that visits the customer with the power to resolve the issues or to include the laboratory directors or the technical director in the problem solution. Customer conferences are held biennially to discuss issues that are important to the customer.

These elements of and emphasis on customer satisfaction and service set CSTA apart. With defense dollars continually at risk of being reduced, CSTA's unique facility survives by ensuring that military and civilian customers are satisfied with testing capabilities and support. This concerted effort on CSTA's part led to its reception of the U.S. Senate Productivity Award for Maryland in the Service Category, with a citation for "commitment to its employees, its customers, the community and continuous improvement of productivity and quality." The Best Manufacturing Practices team found the following practices to be among the best in government and industry.

### 1.2 BEST PRACTICES

The following best practices were identified by the survey team at CSTA:

Item	Page
<b>Data Analysis</b>	<b>5</b>
To accommodate the large volume of data collected during vehicle testing, CSTA has developed software for anomaly analysis in near real time.	

Item	Page	Item	Page
<b>Customer Feedback Program</b>	6	<b>High-Speed Photography</b>	9
CSTA has developed and implemented a customer feedback program that has improved customer relations and improved CSTA's testing program. The backbone of the program is the CSTA Test Performance Rating Questionnaire for direct input from customers.		CSTA has implemented the latest in advanced electronic imaging technology to complement its full suite of traditional high speed visual instrumentation for recording and analyzing test results.	
<b>Oil Analysis</b>	7	<b>Employee Recognition Program</b>	10
CSTA applies oil analysis to determine proper maintenance intervals for Army vehicles, avoiding the procurement of new lubricating oils and saving the unnecessary generation of used oil.		CSTA places a high value on recognizing and rewarding employee accomplishments through the Commander's Quality Awards Program. These awards recognize individuals and teams while providing real benefits in continuous improvement and customer focus.	
<b>Real-Time, On-Site Data Reduction</b>	7	<b>Marketing Program</b>	10
CSTA has dramatically improved data reduction to allow review of test results as they occur. Advances in instrumentation, computers, and software have yielded test site integration for both automotive and ballistic data flow.		CSTA has initiated a marketing program for better workload forecasting and improved relationships with customers.	
<b>Replacement of Low Odor Base Paraffin Solvent in Magnaflux Inspection</b>	8	<b>Customer Relations Program</b>	11
CSTA has replaced Low Odor Base Paraffin Solvent with water as the particle carrier in magnetic particle testing, resulting in reduced hazardous waste generation, reduced process cost, and increased worker safety.		CSTA's customer relations program has improved relationships with long time customers and has helped to develop new customers.	
<b>Firing Impulse Simulator</b>	8	<b>Centralized Resource Scheduling</b>	11
CSTA developed a firing impulse simulator to replicate the effects of gun firing shock on the recoil mechanism on large caliber weapons.		CSTA's automated central support resource scheduling process provides efficient and cost effective allocation of manpower, equipment, instrumentation, ranges, and facilities to support as many as 250 individual test projects at CSTA each work day.	
<b>Virtual Target Scoring/Evasive Target</b>	8	<b>MegaLAT Very Large Article Test Facility</b>	13
CSTA maintains state-of-the-art fire control test facilities housed at three locations to conduct static live fire simulations, dynamic live fire simulations, and dynamic non-firing simulations.		The MegaLAT ship structure produced by CSTA affords its customer the opportunity to conduct a wide range of explosive tests on full-scale mock-up ship sections for evaluation of explosive effects on both structures and internal components within the structures.	
<b>Environmental Noise Management Program</b>	9	<b>Underwater Explosion Test Ponds</b>	14
CSTA has a proactive Environmental Noise Management Program that has reduced the impact to the surrounding communities and provided a better balance between protection of CSTA's mission and community concerns.		The large and small Underwater Explosion Test Ponds constructed by CSTA now offer a large-scale and, in some cases, full-size ship testing capability at significantly reduced cost and environmental impact compared with previous Navy at-sea testing practices.	

### 1.3 INFORMATION ITEMS

The BMP survey team identified the following items as informational at CSTA:

Item	Page
<b>Loose Cargo Simulation</b>	15
CSTA has developed a new standard that ensures consistent packaging testing on similar equipment of varying sizes.	
<b>Mechanical Properties Testing of Woven and Knitted Fabrics</b>	15
CSTA has instituted upgrades in fabric testing to automate the data collection and reporting of the mechanical properties of woven and knitted fabrics.	
<b>Toxic Fumes Measurement</b>	16
CSTA has the capability to analyze the toxic fumes in the occupied area of a vehicle during normal operations or from a test firing.	
<b>Laboratory Vibration Testing</b>	16
CSTA personnel have developed accurate vibration simulation schedules that allow them to conduct valid vibration tests in a laboratory. This capability has improved personnel safety while decreasing the cost of testing.	
<b>Automated Accountability and Control of Ammunition and Explosives</b>	17
CSTA developed an inventory control and accountability system to effectively allow tracking of receipts, issues, and inventory balance of all ammunition and explosives used in testing efforts.	
<b>Automated Propellant Weighing</b>	17
A critical process that has been automated at CSTA addresses the quality control and accountability in processing ammunition.	
<b>Weapons Proofing</b>	17
CSTA is responsible for the proofing, inspection, reassembly, and final shipment of all the Army's large caliber cannons. It performs the final quality assurance function on these cannons to ensure the safety of the gun system.	

Item	Page
<b>Test Fabrication</b>	17
CSTA maintains a local fabrication capability to support testing operations in its 100,000 square-foot facility supporting 45 skilled tradesmen.	
<b>Reclaiming Cutting Oil</b>	18
Aggressive efforts to reduce disposal and related costs associated with spent machine lubricating oils have resulted in significant savings for CSTA.	
<b>Elimination of Freon in Copper Crusher Gauge Cleaning</b>	19
CSTA is using a two-step process with a sand blast pre-clean to eliminate the use of Freon 113 in the cleaning of copper crusher gauges.	
<b>Industrial Radiography</b>	19
CSTA has the capability to perform radiographic inspection on a complete range of test items. These items include welds, ammunition, ammunition components, armor plates, penetration measurements into targets, and basic material conditions such as cracks, voids, and inclusions.	
<b>Video Borescoping</b>	19
CSTA has implemented a video borescoping technique for 25mm guns that provides a permanent videotape record of the inspection.	
<b>CSTA Program Management Information System</b>	19
CSTA developed a successful Program Management Information System. It has helped reduce paperwork, data recording and transmission errors, and key entry requirements, while easing and improving the CSTA cost estimating process.	
<b>Army Test Incident Reporting System</b>	20
The Army Test Incident Reporting System is an automated system used by CSTA for documentation, storage, and retrieval of results for the wide variety and enormous quantity of Army Test and Evaluation Command results.	

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Item	Page	<b>1.4 ACTIVITY POINT OF CONTACT</b>
<b>Total Army Quality Initiatives and Structure</b>	<b>20</b>	For further information on any item in this report, please contact:
Leadership, teamwork, and customer focus have evolved over the past decade at CSTA to produce a business-oriented culture that values its employees, satisfies its customers, and is continuously improving.		Mr. Rick Kost Combat Systems Test Activity STECs-RM-TM Aberdeen Proving Grounds, MD 21005-5059 Phone: (410) 278-3055 FAX: (410) 278-2701

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## SECTION 2

### BEST PRACTICES

#### 2.1 TEST

##### FIELD FEEDBACK

##### Data Analysis

To accommodate the large volume of data collected during vehicle testing, CSTA has developed software for anomaly analysis in near real time. The Vibration Expert System Analyzer (VESA) is a Fortran 77 program that performs the quick look function and recommends continuing or halting the test to correct a problem with the data acquisition system.

During vehicle testing on the test tracks, CSTA instruments the vehicle to measure vibration. The transducer signals run through a signal conditioner and are converted from analog to digital signals which are then transmitted to a receiver. The data is transmitted from the test vehicle (Figure 2-1) to eliminate the need for a second test collection vehicle. Thirty to 60 channels of data are typically collected during each test, and each channel is normally

sampled at a rate of 2000 samples per second. These are typical rates although additional capability exists. Each project contains 600 million to one billion data points with dozens of projects per year. The data is verified on-site using "frmer" and "amdst." Frame errors (data greater than 98% of full scale), wild points (sudden change in adjacent data points), and DC shifts (shifts of greater than 25 counts for 1/6 second) are detected using "frmer," and acceleration amplitude distribution is verified with "amdst." The data is further analyzed post-site for time domain verification and frequency domain verification.

VESA examines the output file which includes the total number of frame errors on all channels, to determine if the file is editable or not (contains more than ten errors), to identify the largest track interval that contains no frame errors, and to identify any channel that is non-editable. A histogram error checking verification is performed to inspect for items such as missing data, noisy data, one-sided data, clipped signal data, discontinuities in the data, and insufficient resolution. A recommendation to proceed with testing is made by VESA based on this analysis.

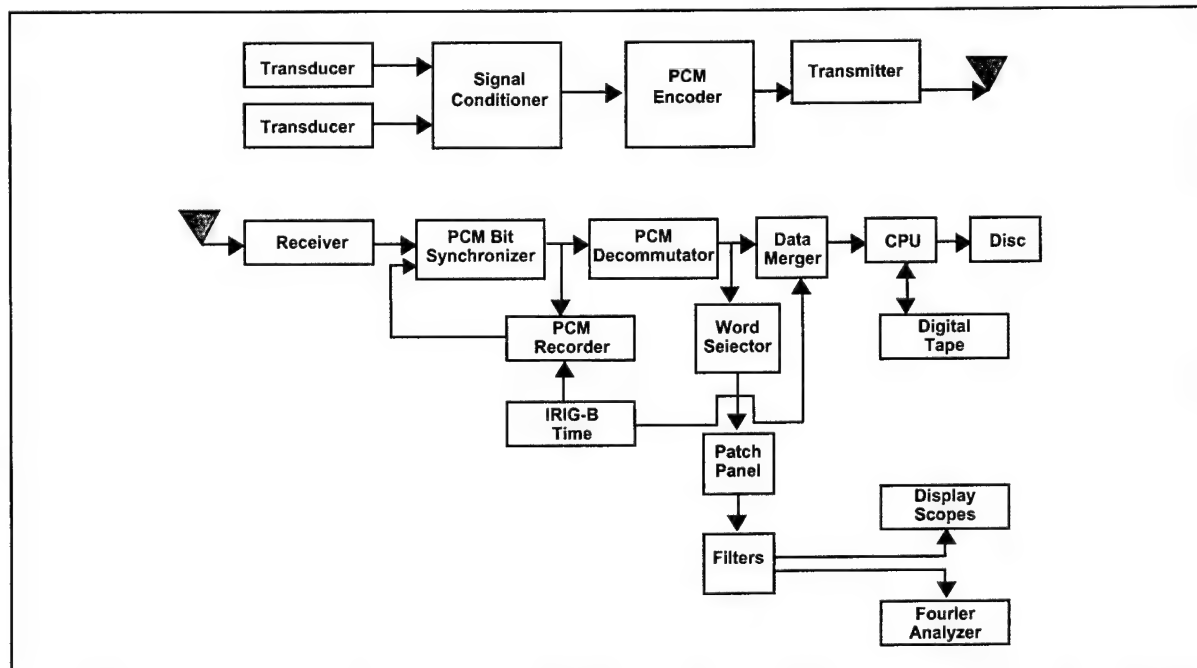


FIGURE 2-1. DATA ACQUISITION SYSTEM

The post-site time domain verification uses "statn" to check for stationarity or time invariance; "kurst" to compute the minimum, maximum, mean, standard deviation kurtosis, and the coefficient of variation of the peak and rms values of each data channel; and "skewk" to compute the weighted moments or weighted excursions about the mean. The post-site frequency domain verification is performed using "PSD" to compute the linear average, standard deviation, and peak spectra over the length of the run, "sigmu" which calculates spectral scatter during the averaging process, and "psgm" which plots the coefficient of variation as a function of frequency for each data channel.

By using these tools that were developed at CSTA, problems with invalid data are eliminated, problems during the testing are detected and can be corrected before proceeding with the testing, the analysis of the data can be performed in short periods of time, and the data collected can also be used to develop the testing specifications for similar vehicles in one and a half days instead of the normal six months.

## Customer Feedback Program

CSTA has initiated a Marketing and Customer Relations Program to retain long time customers and to develop new ones. The Test Performance Rating Questionnaire (Figure 2-2) provides the basis for this effort by allowing customers to provide feedback to CSTA on its performance after each completed test. First mailed in FY91, each questionnaire contains rating categories including technical adequacy, timeliness, cost, and overall rate, and each category can be rated on a scale of 1 to 5. If a rating is low, follow-up actions are initiated to include a phone call from a laboratory director within two days after the questionnaire is returned and a written response within 15 days. This action by CSTA helps ensure that customers are satisfied, and if not, that appropriate corrective measures or explanations are carried out. More than 95% of the ratings from FY91 through FY94 have been average to excellent in the four categories.

TECOM Project No.:						
Test Title:						
Please tell us how we're doing (by filling in the square in the appropriate column for each item listed below):						
		Excellent (5)	Above Average (4)	Below Average (3)	Poor (1)	Does Not Apply
<b>1. Technical Adequacy</b>						
a. Pre-test planning .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Test preparation & setup .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Test execution .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Quality of:						
Test incident reports .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Interim reports .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Final reports .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e. Data accuracy/completeness .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f. Instrumentation/equipment .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g. Facilities/ranges .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>2. Timeliness</b>						
a. Test planning .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Test conduct .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. Test data .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. Test report .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>3. Cost</b>						
a. Reasonableness .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Coordination/justification of cost revisions .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>4. Overall</b>						
a. Communication with the test director .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b. Responsiveness of our personnel .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c. CSTA concern about test quality and timeliness ..		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d. CSTA concern for customer satisfaction .....		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
How can we serve you better? Use the space below to comment on our strengths or weaknesses and any suggestions you may have that would improve the service we provide. Thank you!						
Customer Name (print or type)		Signature		Date		
Telephone Number		Address				

FIGURE 2-2. TEST PERFORMANCE RATING QUESTIONNAIRE

## Oil Analysis

The Petroleum, Oil, and Lubricant group at CSTA is responsible for performing oil analysis on Army vehicles to determine water and sediment contamination, wear metal concentration, viscosity analysis, and trend analysis. Prior to 1983, lubricating fluids in Army vehicles had been changed according to standards or manufacturer-set intervals. CSTA has applied lubricating fluid test methods to determine when fluids must be changed to prevent mechanical damage. Because combat vehicle transmissions contain as much as 50 gallons of lubricant, extended maintenance intervals can significantly decrease the amount of oil purchased to service Army vehicles and the amount of waste oil generated by these vehicles.

The technology available for oil testing at CSTA has significantly improved since the inception of this program. The results of these improvements have included oil sample result turnaround times decreasing from two weeks to three days, and annual hazardous waste generation from testing decreasing from 467 gallons per year to 90 gallons per year.

## TEMP DEVELOPMENT/EXECUTION

### Real-Time, On-Site Data Reduction

With the high volume testing that CSTA conducts, reducing data and supplying it to the customer in a timely manner

has been a demanding and tedious process. Until the early 1980s, five people were required to reduce test data for each test and submit the handwritten results to the Test Director. A typical data reduction loop (Figure 2-3) could require up to seven working days to complete. CSTA determined that real-time, on-site data reduction was needed to better satisfy customer requirements.

Since 1989, CSTA has improved data reduction such that the Test Director and customer can now review test results as they occur. Advances in instrumentation, computers, and software have yielded test site integration capabilities for both automotive and ballistic data flow. Automotive testing on the 40 miles of test track can consistently be repeated through real-time data reduction.

Data from the automotive sensors are processed and transmitted to the receiving station where they are monitored and recorded. Should an operator shift outside of the test parameters, the receiving station transmits a red light signal to the operator. On-board recording (such as the profilometer monitoring test track consistency) is used to ensure test condition repeatability. Because of the amount of data recorded from the test track, predictive analysis can be conducted on new designs. Before a single part is produced, the vehicle design is run through the test track on the computer to determine weak areas.

Test site integration for ballistic data flow has also advanced. Depending on the data, sensor and processing requirements results can now be reviewed in real-time or up

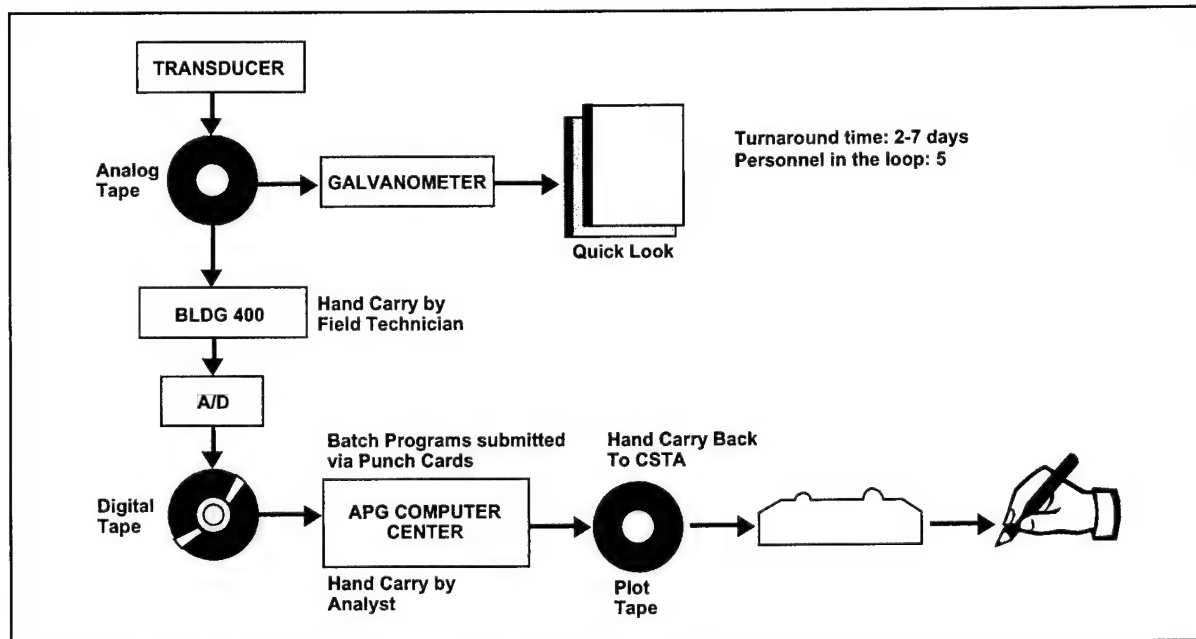


FIGURE 2-3. PREVIOUS DATA REDUCTION LOOP

to a maximum turnaround time of ten minutes. High speed ballistic sensors provide data such as chamber pressure, blast overpressure, and acceleration. Projectile velocity and other information can be recorded from Doppler radar after signal conditioning. Flash X-Ray, target video, and high speed photography are also used. Previously, a black and white photo required one to two days to process at a cost of \$45. The same image can now be obtained in under one second at a cost of less than \$1.

In five years, CSTA has taken complex data reduction and made it user-friendly, on-site, real-time information that is easily accessible. Manpower and time have been reduced, and more data is available for the engineer. In addition to real-time test site feedback, personnel can monitor test results from remote locations through networks. Advances in areas such as data reduction, and customer satisfaction have allowed CSTA to continually expand and improve their test facilities to deal with the increased demand for their services.

## **2.2 PRODUCTION**

### **DEFECT CONTROL**

#### **Replacement of Low Odor Base Paraffin Solvent in Magnaflux Inspection**

By replacing a Low Odor Base Paraffin Solvent (LOPS) with conditioned water as the particle carrier in magnetic particle testing, CSTA has been able to reduce hazardous waste generation, reduce its process costs, and increase worker safety. Magnetic particle testing is used in nondestructive testing on magnetizable materials to detect surface and slightly subsurface discontinuities. Magnetic particle testing consists of three processes including establishing a suitable magnetic flux in the test object, applying magnetic particles in a liquid suspension, and examining the test object under suitable lighting conditions.

CSTA previously used the LOPS petroleum suspension agent in the second step of magnetic particle testing. This agent caused several problems in the inspection process. For example, LOPS had to be collected after the inspection and disposed of as hazardous waste, and LOPS had a flash point of 140 degrees F presenting a constant danger of flash fires. Finally, the inspection personnel were continually exposed to vaporized LOPS which posed a health hazard at high concentrations.

CSTA solved these problems by replacing LOPS with conditioned water as the suspension agent for the magnaflux process. Water eliminated the generation of hazardous waste, eliminated the chance of flash fires, and eliminated the breathing hazard associated with LOPS. Further, the cost of

using this inspection process decreased because conditioned water costs of \$1.28/gallon replaced the \$2.72/gallon costs for LOPS — and there was no disposal cost for the water.

CSTA continued to improve the magnaflux inspection process by switching from traditional contact prods to larger clamps with copper brush contacts. This change more than doubled the contact surface of the inspected item which reduced the amount of heat generated by the process, allowing higher energy levels to pass through the clamps. In turn, greater spacing could be used between contact points to reduce the number of shots required and thus the cost to inspect an object.

## **SPECIAL TEST EQUIPMENT**

### **Firing Impulse Simulator**

CSTA developed a Firing Impulse Simulator (FIS) in response to the increasing cost of live fire testing of large caliber recoil mechanisms. The recently installed FIS is a \$6M facility designed to replicate the firing impulse imparted on a recoil mechanism during live firing. This capability allows recoil mechanisms to be exercised and tested while on the host vehicle, and enables test engineers to look at a recoil system's response over its full range of elevation.

There are several advantages of this facility over live fire testing. For example, the facility is indoors, not weather dependent, and easily set up and run. The simulator also enables engineers to exercise a mechanism in a repeatable fashion to more closely examine any particular phenomena that may occur during testing. Because FIS is computer controlled and fully instrumented, it automatically records the recoil event. It can be operated approximately once per minute thereby enabling engineers to examine the recoil systems' response to repeated rapid firing. However, the most important benefit of the system is reduction in the cost associated with live fire testing of large caliber systems, which averages \$2K per round. The FIS accomplishes the same function for approximately \$35 per cycle.

### **Virtual Target Scoring/Evasive Target**

CSTA maintains three facilities that enable it to conduct dynamic live fire simulations, static live fire simulations, and dynamic non-firing simulations, mostly in large caliber direct fire weapons systems. These three ranges - Trench Warfare I (TWI), Trench Warfare II (TWII), and the Moving Target Simulator (MTS) - allow CSTA to determine the firing accuracy of a weapon system in a fraction of the time and at a substantially reduced cost of just a few years ago. This capability, coupled with the near real-time availability of the firing data, makes this fire control testing range vitally



important. Each range maintains state-of-the-art instrumentation, data acquisition, and data transmission capabilities. The combination of these three major technological areas with complementary capabilities gives CSTA a unique and cost effective test facility.

At TWII, a large caliber direct fire weapon system such as a tank is instrumented with state-of-the-art video equipment and a host of other instrumentation to measure parameters such as gun line-of-sight, reticle position, sight field of view, and digital fire control computer inputs and outputs. Range instrumentation consists of high speed digital cameras for impact scoring, a digital doppler radar for trajectory measurements, and numerous survey monuments out to 3000 meter target range. All signals are monitored real-time from a remote control station. Once a round is fired, the instrumentation allows the control engineers to automatically calculate the theoretical versus the actual trajectory of the round. This is accomplished on site, in near real-time, to allow test engineers to analyze the event prior to firing the next round. This effort saves valuable range time, ammunition, and money. Once a firing platform is characterized in the static mode, it then goes to the MTS.

Data from TWII is automatically available for use at the MTS, thereby enabling test engineers to be prepared to conduct dynamic non-firing simulations. The MTS is a 200-foot diameter, climate-controlled inflatable dome which contains an argon laser. This laser projects a simulated target on the inside of the dome for the test vehicle to track. The test vehicle is fully instrumented to conduct simulated firings against moving targets. This facility compiles the dynamic data necessary for the vehicle to move to the dynamic live fire simulation at TWI. All data is calculated in near real-time and available for use at the other two ranges.

The firing platform is finally tested in the dynamic mode at TWI. This facility provides for fully instrumented moving tank and moving target engagements out to a range of 2400 meters. As in TWII, all events can be recorded using state-of-the-art instrumentation.

## **ENVIRONMENTAL ISSUES**

### **Environmental Noise Management Program**

Since 1984, CSTA has instituted several operational initiatives to reduce environmental noise impact to surrounding communities and to better balance CSTA's mission with community concerns. Before that time, predicting or assessing noise propagation was not conducted because of the tedious mathematical computations required and the lack of adequate weather data. A primitive warning system with a limited number of sensors around the Proving Ground proved inadequate.

A computerized modeling program developed in 1988 by the University of Dayton and the Atmospheric Sciences Laboratory to predict noise propagation was installed at CSTA. The program accounted for meteorological factors that affected noise propagation such as air density, temperature inversions, and wind speed and direction. The meteorological measurements needed to predict noise propagation included surface wind and temperature, and wind and temperature aloft which CSTA has the capability to measure with sensitive ground and airborne sensors. The Noise Model used this meteorological data with the charge weight and firing site to produce a decibel (dB) contour level map for the noise distribution prediction.

CSTA has also installed an updated noise monitoring system. The original system consisted of four monitors developed in 1984 by Construction Engineering Research Laboratory. The upgrade - started in 1991 - includes the addition of 14 Larson Davis Laboratories monitors with plans to order more units as funding becomes available. The monitors stationed around CSTA automatically call in to the base station computer. The data collected is used to verify and update the noise prediction model, respond to noise complaints, and investigate damage claims.

CSTA conducts a daily noise assessment each morning that large caliber firings are scheduled. Weather data is collected and used to generate a predicted noise contour plot for the surrounding area. To validate the model for that particular day, a three-pound charge is detonated and the noise levels in the surrounding communities are measured. Based on these confirmed predicted/monitored levels, appropriate restrictions are implemented. If the predicted noise level is above 130 dB, the firing is postponed, to be resumed by command decision. In the range of 125 dB to 130 dB, the firing is evaluated on a case-by-case basis with approval by the Executive Officer or his designee.

No firings or detonations of any type are conducted weekdays before 6:00 AM and after 10:00 PM, Saturdays before 7:30 AM and after 3:30 PM, Sundays, and holidays. No large caliber firings and no static detonations of five pounds or more are conducted weekdays before 8:30 AM and after 10:00 PM and Saturdays before 8:30 AM and after 3:30 PM. The CSTA commander must approve all other firings.

## **2.3 FACILITIES**

### **FACTORY IMPROVEMENTS**

#### **High-Speed Photography**

In 1989, CSTA realized customer requirements for instantaneous display, lower data acquisition costs, faster

turnaround time, and real-time test monitoring must be met to remain competitive. Therefore, it began to move to video and digital technology for visual imaging.

Several high-speed electronic imaging systems have been adapted for testing to ensure the right tool is used. The Nac Hsv-1000 is a color video system capable of recording up to 1000 frames per second (fps) and has many standard military and commercial uses. The Kodak EM high-speed imager has electronic digital memory, and images are stored in Dynamic Random Access Memory. It continuously monitors test operations at rates of 1000 fps or 6000 split fps. Exposure rates of 10 microseconds and immediate playback of test results in full motion are also available.

To replace or complement high speed film cameras, the Kodak 4540 high speed video system operates from 4500 fps to 40,500 fps and provides electronic imaging. Images are stored electronically in Dynamic Random Access Memory, and immediate playback of test results in full motion is available. The one-shot ballistic digital range camera (Black and White SV-553BR) which operates at a rate of 200 nanoseconds is capable of freezing a projectile in flight for data analysis. Up to 16 cameras can be computer-controlled for one firing and can provide high resolution black and white photographs on site. Data such as pitch, yaw, sabot separation, velocity, and target scoring can be analyzed. Similarly, the color Hadland CSVr provides instant, on-site, high resolution color photographs at 200 nanosecond electronic shutter exposure for capturing in-flight data beyond 2000 meters per second.

CSTA leads the field in ultra high-speed digital imaging with the Ultra Nac High-Speed Imager which records at the equivalent of 20M fps. Through electronic conversions, intensifiers, and computer enhancements, the Ultra Nac produces high resolution images to analyze warhead formation, threat and target interaction, and multiple warhead timing.

Traditional high-speed film instrumentation is also still an effective tool for recording test results. CSTA uses 35mm and 16mm film (10,000 fps) for high resolution color photographs and synchro-ballistic shots to catch a projectile in flight. This equipment is rugged and can be placed in close proximity to the gun, although film processing remains a costly and time consuming process, and cannot begin until the test is completed.

CSTA's advances in electronic imaging complements film cameras and reduces the need for chemical-based film development. In addition, CSTA has met customer requirements by providing real-time, on-site images at a fraction of the cost. Previous costs were almost \$100 for 125 feet of film, and the same data can now be obtained for between \$2 and \$5.

## **2.4 MANAGEMENT**

### **PERSONNEL REQUIREMENTS**

#### **Employee Recognition Program**

CSTA values its employees and believes they are the key to continuous improvement. High level attention and effort are devoted to recognizing the accomplishments of teams and individuals. Two award programs have been established to recognize achievement and promote continuous improvement.

The Commander's Annual Quality Award, first presented in 1990, recognizes team accomplishments. This is an honorary award, and teams are nominated by Quality Management Boards and selected by a special selection committee.

The Commander's Quarterly Quality Award was initiated in 1991 to recognize individual accomplishments. Nominees are selected from completed Total Army Quality (TAQ) Initiatives. It is a monetary award and winners are selected by the TAQ Steering Committee.

Recipients of these awards and other award programs are recognized in several ways including formal award ceremonies at the employee's worksite or station theater, publicity in the CSTA newsletter, and on-the-spot awards. The Commander's Quarterly and Annual Award winners have their photographs and a brief description of their accomplishments displayed prominently on the CSTA Wall of Fame in the entrance of the command headquarters. Other recognition mechanisms include exposure of awardees at various levels throughout the Department of the Army and time off with pay.

The award program has helped instill customer service as a primary task of all employees and also to promote continuous improvement. To date, employees' contributions have resulted in more than 250 completed TAQ Initiatives and more than 25 Process Action Teams chartered to resolve corporate issues.

### **MANUFACTURING STRATEGY**

#### **Marketing Program**

CSTA has initiated a marketing program that has provided better workload forecasting, improved relationships with customers, developed new customers, and produced customer investment in CSTA facilities. The resources required to conduct tests at CSTA are documented by TECOM through the Test Resource Management System (TRMS) database. This database is used to forecast workloads and budget levels for CSTA and the other TECOM test activities.

As workloads were reduced from the defense drawdown effort, better test workload definition was needed to defend budget requests, to obtain CSTA's share of the TECOM workload, and to receive overhead resources such as manpower and dollars from TECOM. Previously, CSTA relied on its customers to enter anticipated test resource requirements into the TRMS database. However, in 1991, CSTA initiated a Marketing and Customer Relations Program with initial marketing visits to major customers to discuss their future test workloads and document these workloads in TRMS for the customer. These initial marketing efforts were very successful as in the case of the first customer visited which produced 69 tests that had not been entered in the TRMS database.

An expanded marketing program was implemented in phases, beginning with the establishment of a marketing/customer relations specialist. The specialist developed new capability briefings, replaced black and white facilities and capabilities books with color pamphlets, and produced specific brochures outlining major CSTA capabilities. Customer awareness training was initiated for the test directors since these individuals maintained the greatest contact with CSTA customers. Updated and expanded displays were prepared for use at conferences and symposiums.

New customers were targeted, resulting in work from sources such as the Navy and Advanced Research Projects Agency. The Office of Research and Technology Applications was established to enter the Cooperative Research and Development Agreement and technology transfer arena.

This successful marketing effort by CSTA has enhanced the workload forecasting capability while providing the facility with new customers, as well as the \$51 million dollars CSTA customers have invested in facilities since the program began.

## Customer Relations Program

Because CSTA has recognized the importance of customer service in an era of decreasing defense budgets, it has implemented an active program to improve customer relations. Customer awareness training is provided for the 250 test directors who maintain close contact with CSTA customers. If issues are identified in the daily communications between the customer and test directors, a special team can visit the customer to resolve the issues or to involve the laboratory directors or the technical director in the problem's solution.

CSTA has also conducted customer conferences to discuss matters important to the customer. The first conference was held in late 1992 with more than 60 customers attending. The two main issues raised by the customers were the need for more cost details in the test estimates and the im-

portance of communication. As a result of this first conference, CSTA now provides an improved cost breakout with each test estimate. Communication is continuously stressed and customer relations training is provided. The second customer conference is scheduled for September, 1994.

## DATA REQUIREMENTS

### Centralized Resource Scheduling

There are as many as 250 daily test projects at CSTA with individual specific resource requirements for manpower, equipment, instrumentation, ranges, and facilities. To manage this demanding and constantly changing workload, CSTA has developed a centralized scheduling process under the ownership of its Resource Coordination Division (RCD). RCD produces monthly, weekly, and daily schedules that distribute resource requirements from a matrix organization of support groups in an optimal way to meet the needs of the test directors.

Before centralized scheduling was implemented, only the firing ranges and some personnel requirements were scheduled on a centralized basis. All other resources were scheduled independently through the individual area supervisors. Test directors had to spend considerable time and effort lining up resources needed for their test projects, often negotiating with respective area supervisors. Priorities were set by availability rather than being driven by customer needs. The only formal schedule that was published was a hand-typed daily firing range schedule that was compiled each day from paper and pencil master sheets. There was little or no coordination between support groups.

Pressure for change came as defense funding was cut back and competition with other test centers for work intensified. Optimizing resources and reducing costs were critical to keeping CSTA competitive and satisfying its customers. Centralized scheduling was needed to control support resources for the more than 700 test programs in progress each year. Close coordination and communication between support groups and test managers became essential to avoid waste, shortages, and crisis management.

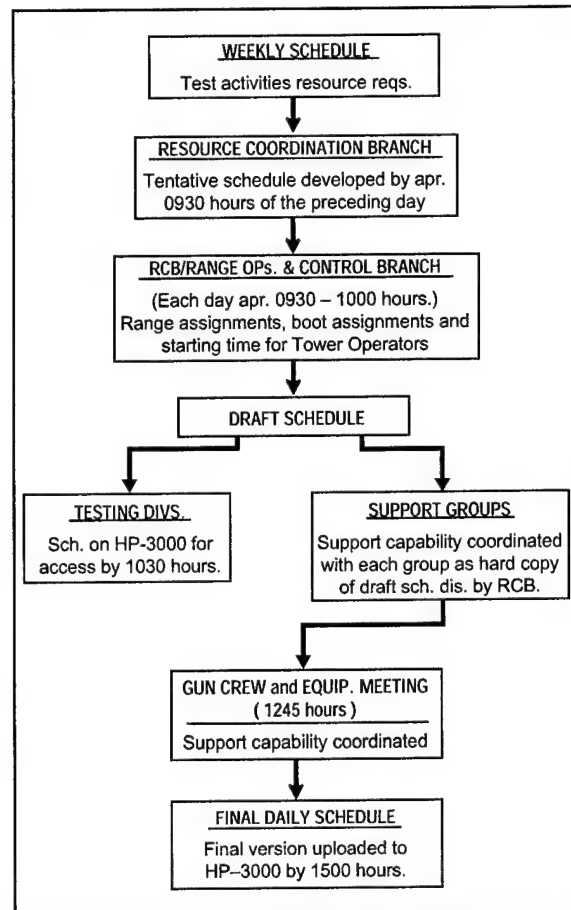
Most scheduling requirements have now been centralized within RCD which schedules 80% of the support resources at CSTA. Those groups not directly scheduled are provided priorities by RCD. These are generally for services such as failure analysis and chemical laboratory services that are difficult to forecast. Formal weekly and daily schedules based on monthly forecasts coordinated with the test directors are published for range firing, automotive, engineering support, and military personnel.

Each of the published schedules is created using its own unique process, although the process flows are similar. The

daily weapons firing schedule provides a typical example. When a firing requirement becomes known (often months in advance) the test director submits a Firing Scheduling Request form. This form details firing support, weapon, and ammunition requirements. It includes the number and types of personnel, equipment and vehicles, instrumentation, and other support resources requested. Based on this input, RCD develops a monthly forecast draft which is sent to each test director on the first of the month for the next month's changes and additions. Changes are made to the database, and the final forecast is published by the 15th. Each week changes are sent to RCD by Tuesday noon for the next week's schedule. Changes are made to the database and totals coordinated with support groups. If necessary, the test directorate supervisors meet at midweek to resolve conflicts. A tentative daily schedule is issued early the following day, reviewed, and finalized. Processing is done on an HP-3000 computer and draft schedules can be reviewed on line via LAN or by printed hard copy. Figure 2-4 presents a flow chart of the daily firing schedule development process.

Priorities are based on milestone schedules and funding posture. Internal work flow priorities are based on event sequences, support matrix capacities, and intelligent intervention by RCD schedulers based on communication, knowledge of the overall picture, and experience. Precedence lists have been established for recurring situations. When conflicts arise, they are elevated to successively higher levels within the command as appropriate for resolution.

Benefits of automating this process over the previous handwritten system are increased accuracy and efficiency. Data storage has greatly improved, and most paper has been eliminated. The process facilitates communication and coordination, allowing more to be accomplished with fewer resources and at a lower cost. Forecasting and after-action capabilities are also enhanced. The system has removed the burden of setting priorities from the first line supervisors. Priorities are now established based on planned requirements set by the test directors with corporate involvement.



**FIGURE 2-4. DAILY FIRING SCHEDULE DEVELOPMENT PROCESS**

## TECHNICAL RISK ASSESSMENT

### MegaLAT Very Large Article Test Facility

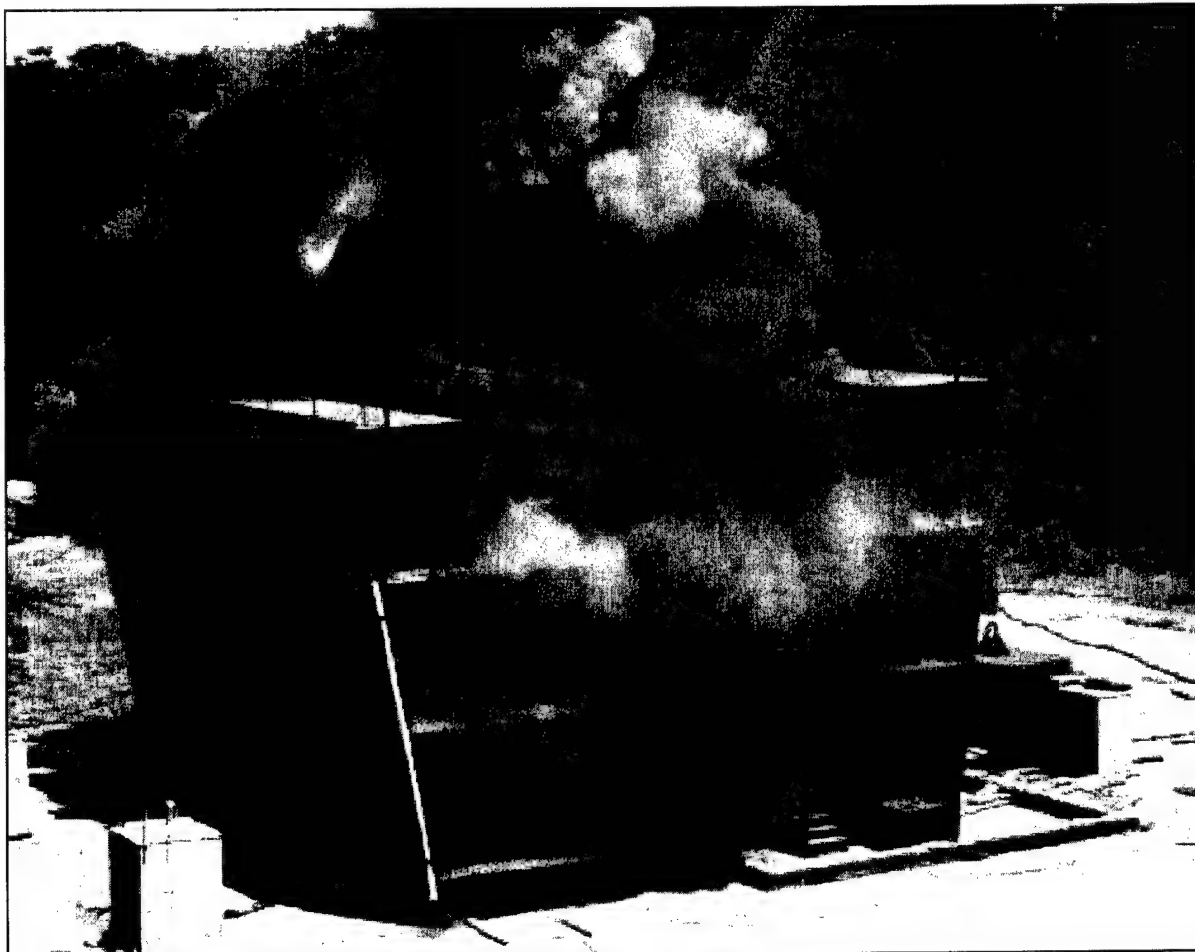
CSTA produced a Large Article Test (LAT) structure to evaluate the effects of internal blast. This facility - a ship section - was constructed to meet Navy ship designers' needs for data on the vulnerability and survivability of current and next-generation ship structures and equipment. As a result of the significant successes achieved in the LAT test, CSTA has constructed a larger follow-on ship section called the MegaLAT (Figure 2-5).

The MegaLAT offers the customer the capability to produce battle damage effects on a ship's combat control computers and its peripheral systems when subjected to attack by realistic anti-ship threats. The structural integrity testing capability of the earlier LAT also resides in the new MegaLAT. Additionally, a full range of electrical power, heating, and cooling can be provided to

installed components or systems during testing, thereby promoting a highly realistic operating environment. CSTA can also provide explosive testing while installed systems such as transmitting radar are actually in full operation.

To support the MegaLAT, CSTA has developed the capability to fabricate full-scale ship structures such as hull, decks, and bulkheads to be tested. To enhance capabilities in this area, CSTA has certified welders to MIL-STD-248D, has conducted material testing of plate stock, and has performed both magnetic particle and radiographic inspections as required by applicable MIL-STDs.

CSTA's fabrication facility is currently being modified to allow indoor fabrication of ship structures, similar to advanced worldwide shipbuilding techniques. Although the LAT and MegaLAT are large sections of ships, CSTA can readily fabricate other large and very large commercial or military structures of any reasonable size to meet customers testing requirements.



**FIGURE 2-5. MEGALAT TEST FACILITY**

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## Underwater Explosion Test Ponds

In response to the Navy's continuing requirement for underwater explosion (UNDEX) tests on ships, submarines, and installed equipment, CSTA has constructed small and large UNDEX test ponds. A large UNDEX pond is shown in Figure 2-6.

Reaching dimensions of up to 1000 feet in diameter and 150 feet deep, the two UNDEX ponds provide CSTA with the capability of conducting underwater explosion shock tests of large scale submarine and surface ship structures

weighing up to 2200 tons. Each test can be fully instrumented to include pressure measurements, acceleration, strain, velocity, ballistic shock, vibration, flash, and thermal effects. In addition, high speed and ultra high speed film and video imaging can be provided.

UNDEX tests can now be performed by CSTA in its ponds, thereby avoiding the adverse environmental impacts of the current Navy at-sea testing practices. Further, test costs utilizing the UNDEX ponds are significantly less than the cost of similar tests conducted at sea. This results in a considerable savings to Navy programs.



**FIGURE 2-6. LARGE UNDEX POND**

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# SECTION 3

## INFORMATION

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### 3.1 DESIGN

#### DESIGN REQUIREMENTS

##### Loose Cargo Simulation

CSTA developed a new standard for ensuring consistent loose cargo packaging testing on similar test equipment of varying size. The test variation in testing was discovered during a packaging qualification test on grommets by the Army Research and Development Engineering Center (ARDEC) to protect the rotating bands of the 105mm projectile during transportation. The packaging test was developed to simulate loose projectiles in the bed of a tactical wheeled vehicle.

During the loose cargo lab testing at CSTA, it was noted that the rotating bands on the 155mm projectile were being damaged by the failure of the grommets to remain secure over the rotating bands. These results did not match the results obtained by ARDEC during the development of the grommet design. Consequently, CSTA placed loose grommets in an instrumented tactical vehicle to evaluate the actual field effects on the ammunition. This evaluation demonstrated damage similar to the original CSTA lab test.

Following these results, a wireless environmental data recorder was placed in the packaging tester to gather data on the dynamic characteristics of the test equipment. The data recorder has the advantage of being hand portable and self-contained with the ability to measure triaxial acceleration. The measurements were taken several times to ensure a good presentation of the loose cargo test equipment at CSTA. After the baseline was established for the large packaging tester at CSTA, the same baseline establishment was performed on the small test equipment at ARDEC. The dynamic characteristics at ARDEC did not duplicate those generated at CSTA. This helped explain why different results were obtained at CSTA when compared to ARDEC's development results. By increasing the RPM input into the ARDEC equipment, a similar dynamic output to the CSTA equipment was achieved. For a setting of 300 RPM on the CSTA tester, a setting of 320 RPM on the ARDEC tester was needed to duplicate a similar output. Three hundred RPM was selected because 20 minutes at 300 RPM on the CSTA equipment simulates a trek of 150 miles with loose cargo in a tactical wheeled vehicle.

Several other test activities have been contacted to determine if a standards covering this situation were uniform, and since they were not, CSTA has developed and prepared a standard which will be presented to NATO for acceptance. The standard will then be evaluated for incorporation into MIL-STD-810 and TOP-4-2-602. CSTA is also continuing work with Cranfield University (United Kingdom) to understand why the output of similar equipment varies.

In making these improvements, CSTA continues to ensure that only safe designs pass through CSTA testing. These types of improvements provide worldwide recognition to CSTA as a leader in transportation and vibration testing.

### 3.2 TEST

#### UNIFORM TEST RESULTS

##### Mechanical Properties Testing of Woven and Knitted Fabrics

CSTA has implemented upgrades in fabric testing to automate the data collection and reporting of the mechanical properties of woven and knitted fabrics. The fabrics designed to camouflage and protect military vehicles are exposed to various environmental conditions prior to testing. The traditional methodology required the conversion of raw data captured on a strip chart recorder into useful technical results. To obtain the desired final information, numerous manual measurements were recorded in tabular form, converted to a conventional format for calculation purposes, and entered into computer tables for report generation. This process required many steps which created the opportunity for error in the final report.

Preliminary improvements included locating a computer adjacent to the test equipment for direct data input, conversion, and reporting. Additionally, the data could more readily be manipulated should further analysis be desired. CSTA has initiated action to fully automate the data collection process to reduce the possibility of error. An INSTRON Series 9 software package has been installed to directly feed the raw data from the fabric testing equipment into the computer for report generation and analysis.

These improvements have increased the execution and reporting efficiency by 30%-50%. An increase in accuracy has also been achieved by eliminating systematic and random errors associated with reading data from the strip chart recorder and also by eliminating the errors caused by

transcription. Customer responsiveness has been enhanced by providing immediate feedback during testing, utilizing the computer's ability to sort and analyze data quickly, and allowing flexibility in reporting formats.

## DESIGN LIMIT

### Toxic Fumes Measurement

CSTA has improved its ability to measure levels of toxic fumes and gasses in the confined spaces of vehicles during testing. Before 1983, the only dedicated real-time analyzers available were for carbon monoxide,  $\text{NH}_3$ , and nitrogen dioxide. Samples of other species were collected with vacuum cylinders for laboratory analysis with a gas chromatograph. Since 1983, however, significant improvements have been made in the equipment capabilities.

CSTA performs toxic fume and gas measurements on live fire (vulnerability), automotive, weapons, and fire extinguishing systems in an effort to protect soldiers from the effects of toxic fumes and gasses. Fumes can originate from the firing of the gun on a tank, the exhaust from the engine of the tank being ingested into the ventilation system, or from the tank being hit by a round of ammunition. CSTA monitors and analyzes the air in the inhabited sections of the vehicle during test operations to detect any toxic gases produced. Real time analysis is performed for  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{NH}_3$ ,  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{NO}$ , Halons, and  $\text{O}_2$  depletion. Collection for laboratory analysis is performed for total particulates, respirable particulates,  $\text{HF}$ ,  $\text{HCl}$ ,  $\text{HBr}$ ,  $\text{HCN}$  acid mists, fuel and oil mists, aldehydes, ketones, organic compounds,  $\text{Pb}$ ,  $\text{Cu}$ , and other metal fumes.

Toxic fumes measurement requires several different pieces of equipment, as shown in Table 3-1.

### Laboratory Vibration Testing

CSTA conducts vibration testing on Army ammunition and various pieces of hardware carried aboard Army vehicles to ensure the rounds will not accidentally detonate during vehicle operations. Other components are tested to ensure they will perform reliably when subjected to the vibrations inside operating vehicles.

Because of safety and economic constraints, CSTA has performed these vibration tests in a laboratory environment designed to simulate the vibrations that the ammunition and hardware undergo in field use. To develop tests that accurately portray field vibration conditions, CSTA recorded representative field data from tracked and wheeled vehicles. From this data, laboratory vibration schedules were developed that subject the test objects to typical field use vibrations.

The capability to perform vibration testing in a laboratory has resulted in several benefits. First, personnel are protected from possible ammunition detonation because each type of ammunition can be thoroughly tested under multiple scenarios before being sent to the troops. Secondly, the cost of conducting tests is greatly reduced since a vibration simulator is less expensive to operate than the vehicle being simulated. Finally, the time to conduct tests is greatly compressed; for example, 6000 miles of tracked vehicle testing can be simulated in four hours.

During the construction of this laboratory, barricades were required around the vibration test beds to protect personnel

**TABLE 3-1. EQUIPMENT FOR TOXIC FUMES MEASUREMENT**

Non-dispersive infrared analyzers for $\text{CO}$ , $\text{CO}_2$ , Halons, ammonia	(BINOS IR)
Non-dispersive ultraviolet-visible analyzers for $\text{SO}_2$ , $\text{NO}_2$	(BINOS UV/US)
Paramagnetic analyzers for $\text{O}_2$	(Rosemount)
Chemiluminescent analyzers for $\text{NO}$ , $\text{NO}_2$ or $\text{NO}_x$	(TECO)
Portable electrochemical monitors for $\text{CO}$ , $\text{O}_2$ , $\text{NO}_2$ , $\text{SO}_2$ and combustible gasses	(Exotox)
Portable photoacoustic infrared analyzers for numerous gasses/vapors	(B&K)
Pulsed fluorescent analyzers for $\text{SO}_2$	(TECO)
FTIR spectrometer (gasses)	
ICP spectrophotometer (metals)	
GC/MS (gasses)	



in case of an ammunition explosion during testing. The cost estimate to build this facility using traditional reinforced concrete barricades was approximately \$26M. CSTA needed the facility but lacked adequate funding for the traditional barricades. To solve this problem, CSTA developed and tested a new barricade construction technique which consists of approximately two feet of sand sandwiched between two steel panels. Using the sandwich construction technique, the new facility was constructed at a cost of \$5.6M.

### **3.3 FACILITIES**

#### **DEFECT CONTROL**

##### **Automated Accountability and Control of Ammunition and Explosives**

CSTA developed an inventory system to effectively track receipts, issues, and inventory balances of all ammunition and explosives used in its testing. Previously, CSTA maintained a monthly inventory process that was labor intensive and could not continually and accurately provide all information required by explosives users. The monthly inventories were done by hand on multi-page forms, and balances were tallied by hand on hard card inventory records. CSTA recognized the need to reduce time spent conducting physical inventories, maintain records of transactions and balances, and maintain positive control of explosive limits for storage site locations.

An internally-developed computer program allows CSTA to reduce monthly inventory preparation time, track material issues and receipts automatically, provide instant quantities and Net Explosive Weight of explosives in storage, and identify where these explosives are stored. Since implementing this process, monthly inventory preparation time has been reduced from two days to two hours, and the information is shared with all personnel who need the information via the LAN on a real-time basis.

##### **Automated Propellant Weighing**

CSTA has automated the critical process of quality control and accountability in processing ammunition. Weapons systems testing at CSTA requires extreme accuracy and repeatability on all propellant and powder charges used in the test ammunition. Prior to changing the propellant weighing system, CSTA personnel weighed each charge independently on shadowgraph scales, recorded the weight on data sheets, and then had the scales reading verified by the test director responsible for that test. This process was time consuming, was subject to operator error, and unnecessarily exposed personnel to risks associated with ammunition assembly.

Between 1991 and 1992, CSTA surveyed the market for an electronic digital scale that could be used to assist in these tasks. Because such a scale with the necessary safety requirements, variable range, repeatability, and preciseness was not available, CSTA commissioned the Fairbanks Scale Company to develop one. The design requirements included a system that would be explosion proof, have a digital readout capability, have computer and printer interface capability, be user friendly, and maintain weight accuracy from a few grains to several pounds. Fairbanks developed and produced the scale while CSTA personnel developed the computer program to interface with the hardware.

Using this system has afforded CSTA several benefits including:

- Reduced personnel exposure since a test director no longer has to verify the weighing of each charge
- Faster and more precise digital scales
- A computer printout to provide a record and verification of the weights
- More accurate test data to enhance the validity of the weapons systems test.

##### **Weapons Proofing**

CSTA is responsible for the proofing, inspecting, reassembling, and shipping of all Army large caliber cannons. By performing the final quality assurance functions on these cannons, CSTA maintains the safety of the gun system.

CSTA receives large caliber gun tubes from Watervliet Arsenal and recoil mechanisms from the Rock Island Arsenal. These major subassemblies are then inspected, assembled, and proof tested. Proof testing consists of firing three standard rounds through the gun and then one "super slug." The standard rounds subject the cannon to typical stresses, while the super slug subjects the recoil to more severe stresses than normally experienced during its service life.

Once the cannon system is proofed, it is broken down, cleaned, and inspected. The gun tubes are cleaned in the traditional fashion, while the breech ring assembly and other small components are placed in a hot-water-based, high pressure parts washer. Inspection consists of both physical and magnetic particle inspection processes. Once the gun passes inspection, it is then prepared for shipment to its final destination.

#### **PRODUCTION FABRICATION**

##### **Test Fabrication**

CSTA maintains a local fabrication job shop to support test operations. The organization - known as the Experimental

Fabrication Branch—consists of two sections which contain 45 skilled tradesmen in Machine Shop and Welding/Sheetmetal to accomplish the fabrication mission. The Experimental Fabrication Branch maintains a full capability throughout its over 100,000 square-foot facility. The complex contains a 75/15 ton craneway which runs the length of the facility, providing the capability to handle the largest of test vehicles and fixtures.

The Machine Shop Section consists of a large number of machine tools boasting digital and NC/CNC capabilities. The CNC machine tools are locally programmed through a DNC network. This allows CSTA to perform most cutting and turning operations with the speed and accuracy necessary to support the precision requirements of the customer.

The Welding section maintains the ability to cut and weld standard structural materials, armor plate, and even titanium and stainless. This is accomplished through the use of oxyacetylene, water jet, and plasma cutting machines. Assembly of components is performed through a full range of welding capabilities that includes a pulse arc welding machine and a submerged arc welding machine. The Ex-

perimental Fabrication Branch redesigned a nose cup to use on the plasma cutting machine. There was a short life on the factory bronze cups, and by modifying the bronze cup to accept a stainless nose, the shop has seen a sixfold increase in the useful life of the cup.

The Sheetmetal area maintains a full metalforming capability in forming, shearing, cutting, and braking.

## ENVIRONMENTAL CONCERNS

### Reclaiming Cutting Oil

Aggressive efforts to reduce disposal and related costs associated with spent machine lubricating oils have resulted in significant savings for CSTA. Prior to making recent changes in the way that spent coolants were treated, CSTA was purchasing and disposing of 400-600 gallons of coolant per year. This usage was excessive, and the related machine down time resulted in 300-400 man hours of lost productivity from time spent in cleaning machines and replacing spent coolants. Figure 3-1 presents the savings experienced prior to and after improvement efforts.

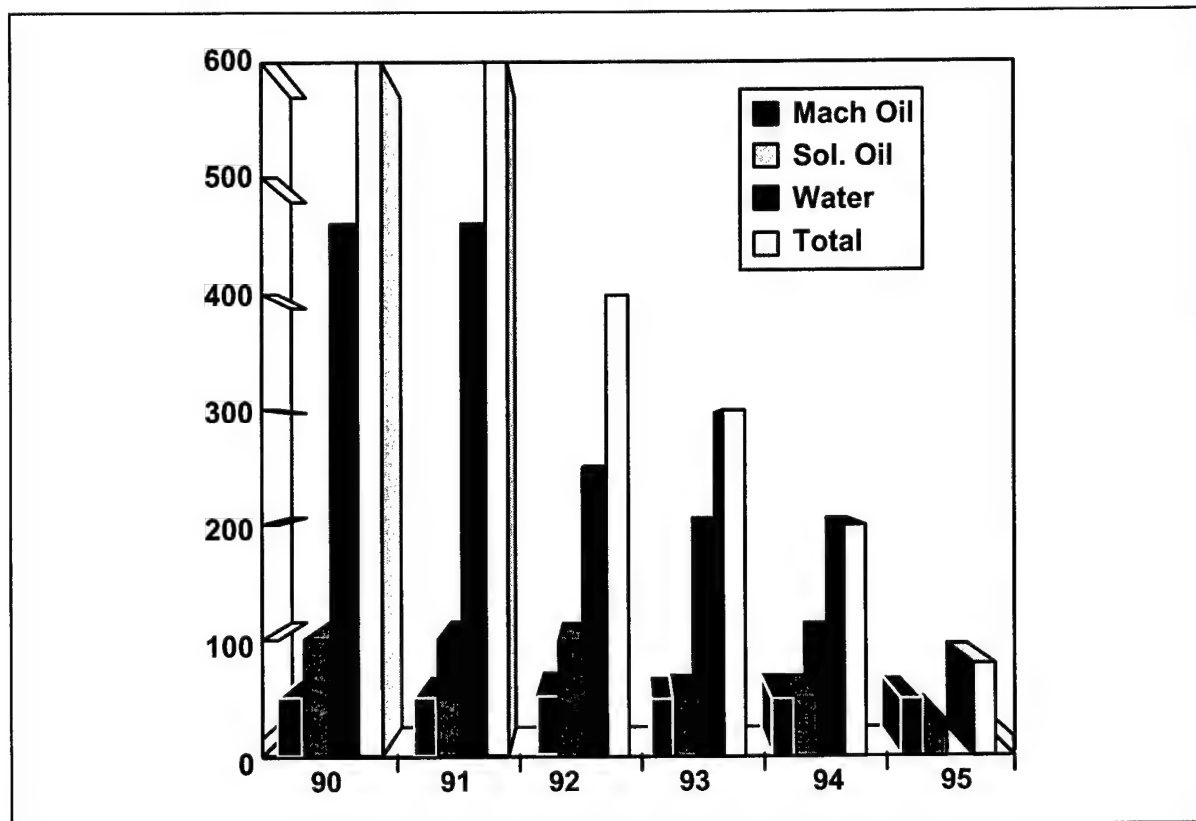


FIGURE 3-1. REDUCTION OF WASTE OIL

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Improvements include introducing a bactericide to the coolants and using an inexpensive oil skimmer manufactured by Master Chemical Corporation to skim off machine oils. Future improvements consist of a total coolant management plan, introduction of a filtering system to reuse the coolant, and implementation of an environmental separation and purification system.

### **Elimination of Freon in Copper Crusher Gauge Cleaning**

CSTA is using a two-step process with a sand blast pre-clean to eliminate the use of Freon 113 in the cleaning of copper crusher gauges. CSTA uses copper crusher gauges to measure the pressure in gun tubes during firing. Two of these gauges are used each time a gun is fired, resulting in a large number of gauges to be cleaned daily. The previous cleaning process involved soaking the gauges in a heated, ultrasonically activated Freon bath for 45 minutes.

Due to new environmental regulations and the cost increase of a 55 gallon drum of Freon 113, CSTA has devised an alternative cleaning process. The new process has an additional preliminary step in which the gauges are sand blasted to remove the gross gun firing residue. This pre-cleaning step has reduced solvent usage by 50-70% since the solvent is not being contaminated by the gun firing residue removed by the sand blasting process. Additionally, the overall cleaning time has been reduced by 50%.

The next step planned to improve copper crusher gauge cleaning will be to eliminate the uses of Freon 113 solvent in the process. In place of Freon, an air bubbler filled with Safety Kleen solvent will be used to clean the gauges after they have been sand blasted and an acetone dip will be used to remove any residual solvent.

## **FACTORY IMPROVEMENTS**

### **Industrial Radiography**

CSTA has developed several capabilities to perform radiographic inspection of a variety of items of many different sizes. X-ray units span a range of 20 KeV to 11 MeV to inspect items from combat boots and helmets to tank hulls. Inspections can be performed on materials from thin ceramics and composites to 24-inch thick steel. Real time inspections can be performed, or film can be used for greater sensitivity. All x-ray units below 4 MeV are portable for field use. Items up to 20 tons can be manipulated in the x-ray rooms with cranes. Large doors allow items on trailers or large vehicles to be inspected. These capabilities have been used by the Army, Navy, NASA, foreign governments, and Baltimore Gas and Electric Company.

### **Video Borescoping**

CSTA has implemented a video borescoping technique for 25mm guns that provides a permanent videotape record of the inspection. This method provides a major benefit in that the video record is not subject to the ambiguity of a written narrative.

Gun tubes are required to be inspected periodically for wear, erosion, and cracking. The inspection documents tube degradation throughout the testing process and assesses the safety of the tube. The previous process used a conventional light borescope that was manually moved, and anomalies were manually recorded in narrative form. This method was highly subjective and operator dependent. The inspectors would record information differently depending on who was conducting the inspection. This resulted in discontinuities between the data and the previous inspection.

Another process was necessary to accommodate a significant increase in inspections required for the 25mm tubes and the need for a quicker turnaround time. A video borescoping system was developed using off-the-shelf equipment that included a video camera, monitor, video recorder, and a metal positioning track for the borescope.

Using the new setup allows the inspector and the customer to view the gun bore surface simultaneously. A permanent record of each inspection is maintained for future reference on videotape. The inspection time was decreased by 25-50% or better depending on tube condition. The turnaround time for the inspection is now less than one hour and is no longer dependent on tube condition. The subjectivity of the written narrative description has been eliminated by storing the visual record.

## **3.4 MANAGEMENT**

### **DATA REQUIREMENTS**

#### **CSTA Program Management Information System**

A CSTA-developed Program Management Information System (PMIS) has provided a management information tool to complement the TECOM TRMS while providing necessary additional details of skills, facilities, and equipment resource requirements to accomplish the wide range of tests conducted by CSTA. Reporting program management information to TECOM under the existing TRMS did not provide sufficient information to meet widely varied management information requirements of CSTA to effectively manage the average 160-250 tests conducted daily. Initial attempts to develop a management information

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system to supplement TRMS using ARTEMIS and TIMELINE (SYMANTEC) software proved too difficult. CSTA changed to a TIMELINE-only based system, applying dBase IV software in conjunction with TIMELINE 5.0 to achieve the current PMIS capability.

The PMIS system now offers CSTA managers, test directors, and support staff with a PC-based, on-line, management tool. As a fully automated system at both the detail and summary levels, a wide range of information is readily available for structured development of cost estimates, workload forecasting, and schedule performance monitoring across all levels and functions of CSTA testing.

The advantages offered by the PMIS system include the reduction of manual calculation and data entry/transmission errors, reduction in key entry requirements, and significant improvements in the CSTA cost estimating process.

## **QUALITY ASSURANCE**

### **Army Test Incident Reporting System**

The Army Test Incident Reporting System (ATIRS) is the latest and most improved automated data collection system in use by TECOM. Evolved from 24 years of data collection efforts, ATIRS is now an HP3000 computer-based system networking eight Army testing activities, including TECOM.

The ATIRS HP3000 is a POSIX-based system using an Image 3000 database and V/3000 menu-driven software with both Query language and Pascal programming language. One of the primary advantages of the ATIRS system is that information access through PC-type computers is now possible. It also has open architecture, is free from security risk, and allows the use of standard hardware and software throughout TECOM.

Today, there are 160 users on the ATIRS system, from 39 private and government organizations. Each user has full on-line access to the results of 1750 test programs and 5745 databases. Included are more than 104,000 Test Incident Reports from CSTA as well as others from White Sands Missile Range, Yuma Proving Ground, and Redstone Technical Test Center.

Future enhancements of the system include automation of electronic handwritten data collection, incorporation of digital pictures, and indexing of most Test Incident Report data elements.

### **Total Army Quality Initiatives and Structure**

CSTA's Total Quality journey began in the mid-1980s by working in partnership with employee unions and management to implement quality circles and employee involve-

ment programs. These TQM initiatives have come to be known in the Army as Total Army Quality (TAQ). In the late 1980s, a Total Quality Steering Committee was formed at CSTA which led to the development of the activity's vision, quality policy, and goals. Training in all aspects of Total Quality was undertaken for management, employees, facilitators, and Process Action Teams.

By the early 1990s, these efforts were yielding results. A strong customer focus and emphasis on marketing was developing, improvements such as project management automation were implemented, and successful employee recognition programs were in place. The success of TAQ efforts was demonstrated by CSTA's receiving the 1990 Senate Productivity Award for Maryland. The command applied for other awards such as the Federal Quality Institute's Quality Improvement Prototype Award not only for recognition purposes but also as a self analysis and feedback tool. Recent efforts have included the development of a Strategic Quality Plan which establishes annual objectives. Biennial customer conferences have been set up that involve CSTA's customers that provide feedback for continuous improvement, and contribute to marketing and business development efforts.

CSTA's vision is to be recognized by its customers as a provider of world-class, environmentally compatible technical test services. This is being realized by putting the customer first with teamwork. CSTA's quality policy demands high quality test products delivered on schedule at the agreed-to price. It is implemented by focusing on customer satisfaction, employee involvement, and continuous improvement, and it is producing results in its reputation as a "can do" unit, high workforce pride, awards and recognition outside the Department of the Army, and reliance on CSTA as the center for testing land tactical vehicles.

The CSTA quality structure is led by a TAQ Steering Committee composed of senior executives and managers. It owns the TAQ process and oversees major decisions, training, and recognition. Under the Steering Committee, cross-functional management teams are responsible for improving customer and supplier relations and for chartering and managing PATs. CSTA PATs are ad hoc employee teams tasked to review a specific process and provide recommendations for improvement. To date over 250 documented initiatives have been completed to eliminate or reduce obstacles to quality and timeliness, or cost of CSTA products and services. Employee-generated improvements that are fully implemented are called TAQ initiatives.

Leadership, teamwork, and customer focus are the key ingredients to CSTA's approach to Total Quality. Evolving over the past decade, this approach has produced a business oriented culture that values its employees, satisfies its customers, and is continuously improving.

# APPENDIX A

## **TABLE OF ACRONYMS**

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<b>Acronym</b>	<b>Definition</b>
ARDEC	Army Research and Development Engineering Center
ATIRS	Army Test Incident Reporting System
CSTA	Combat Systems Test Activity
dB	Decibel
FIS	Firing Impulse Simulator
fps	Frames Per Second
LOPS	Low Odor Base Paraffin Solvent
MTS	Moving Target Simulator
PMIS	Program Management Information System
RCD	Resource Coordination Division
TAQ	Total Army Quality
TECOM	Test and Evaluation Command
TRMS	Test Resource Management System
TWI	Trench Warfare I
TWII	Trench Warfare II
UNDEX	Underwater Explosion
VESA	Vibration Expert System Analyzer

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## APPENDIX B

### ***BMP SURVEY TEAM***

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<b>Team Member</b>	<b>Agency</b>	<b>Function</b>
<b>Bob Jenkins</b> (703) 602-3003	<b>NAVSEA</b> Washington, DC	<b>Team Chairman</b>
<b>Amy Scanlan</b> (703) 271-9055	<b>BMP Representative</b> Washington, DC	<b>Technical Writer</b>

#### **DESIGN/TEST TEAM**

<b>Larry Robertson</b> (812) 854-5336	<b>Crane Division</b> <b>Naval Surface Warfare Center</b> Crane, IN	<b>Team Leader</b>
<b>John Carney</b> (703) 602-3003	<b>Carderock Division</b> <b>Naval Surface Warfare Center</b> Washington, DC	
<b>Bruce Cummings</b> (812) 854-5380	<b>Crane Division</b> <b>Naval Surface Warfare Center</b> Crane, IN	

#### **PRODUCTION/FACILITIES TEAM**

<b>Don Hill</b> (317) 353-3781	<b>Aircraft Division - Indianapolis</b> <b>Naval Air Warfare Center</b> Indianapolis, IN	<b>Team Leader</b>
<b>Jed Ryan</b> (703) 663-8868	<b>Naval Surface Warfare Center</b> <b>Dahlgren Division</b> Dahlgren, VA	
<b>Jeff Parks</b> (313) 574-5161	<b>U.S. Army Tank Automotive Command</b> San Antonio, TX	

#### **MANAGEMENT/LOGISTICS TEAM**

<b>Rick Purcell</b> (703) 271-9055	<b>BMP Representative</b> Washington, DC	<b>Team Leader</b>
<b>John Bissell</b> (703) 602-4185	<b>NAVSEA</b> Washington, DC	
<b>Mitch Ammons</b> (615) 576-6982	<b>Martin Marietta Energy Systems, Inc.</b> Oak Ridge, TN	

## APPENDIX C

### PROGRAM MANAGER'S WORKSTATION

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The Program Manager's Workstation (PMWS) is a series of expert systems that provides the user with knowledge, insight, and experience on how to manage a program, address technical risk management, and find solutions that industry leaders are using to reduce technical risk and improve quality and productivity. This system is divided into four main components; KNOW-HOW, Technical Risk Identification and Mitigation System (TRIMS), BMP Database, and Best Manufacturing Practices Network (BMPNET).

- **KNOW-HOW** is an intelligent, automated method that turns "Handbooks" into expert systems, or digitized text. It provides rapid access to information in existing handbooks including Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), MIL-STD-2167/2768, SecNav 5000.2A and the DoD 5000 series documents.

- **TRIMS** is based on DoD 4245.7-M (the transition templates), NAVSO P-6071 and DoD 5000 event oriented acquisition. It identifies and ranks the high risk areas in a program. TRIMS conducts a full range of risk assessments throughout the acquisition process so corrective action can be initiated before risks develop into problems. It also tracks key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities in the development and acquisition process.
- The **BMP Database** draws information from industry, government, and the academic communities to include documented and proven best practices in design, test, production, facilities, management, and logistics.

Each practice in the database has been observed and verified by a team of experienced government engineers. All information gathered from BMP surveys is included in the BMP Database, including this survey report.

- **BMPNET** provides communication between all PMWS users. Features include downloading of all programs, E-mail, file transfer, help "lines", Special Interest Groups (SIGs), electronic conference rooms and much more. Through BMPNET, IBM or compatible PC's and Macintosh computers can run all PMWS programs.

- To access **BMPNET** efficiently, users need a special modem program. This program can be obtained by calling the BMPNET using a VT-100/200 terminal emulator set to 8,N,1. Dial (703) 538-7697 for 2400 baud modems and (703) 538-7267 for 9600 baud and

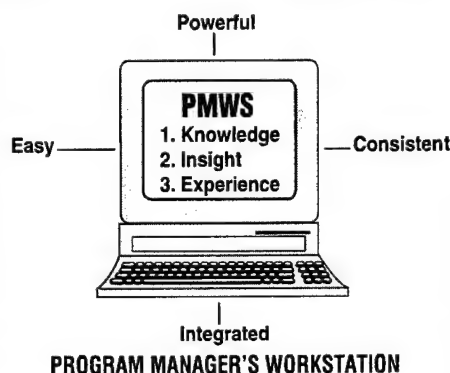
14.4 kb. When asked for a user profile, type: DOWNPC or DOWNMAC <return> as appropriate. This will automatically start the Download of our special modem program. You can then call back using this program and access all BMPNET functions. The General User account is:

USER PROFILE: BMPNET

USER I.D.: BMP

Password: BMPNET

If you desire your own personal account (so that you may receive E-Mail), just E-Mail a request to either Ernie Renner (BMP Director) or Brian Willoughby (CSC Program Manager). If you encounter problems please call (703) 538-7799.





## APPENDIX D

### NAVY CENTERS OF EXCELLENCE

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#### **Automated Manufacturing Research Facility** (301) 975-3414

The Automated Manufacturing Research Facility (AMRF) – a National Center of Excellence – is a research test bed at the National Institute of Standards and Technology located in Gaithersburg, Maryland. The AMRF produces technical results and transfers them to the Navy and industry to solve problems of automated manufacturing. The AMRF supports the technical work required for developing industry standards for automated manufacturing. It is a common ground where industry, academia, and government work together to address pressing national needs for increased quality, greater flexibility, reduced costs, and shorter manufacturing cycle times. These needs drive the adoption of new computer-integrated manufacturing technology in both civilian and defense sectors. The AMRF is meeting the challenge of integrating these technologies into practical, working manufacturing systems.

#### **Electronics Manufacturing Productivity Facility** (317) 226-5607

Located in Indianapolis, Indiana, the Electronics Manufacturing Productivity Facility (EMPF) is a National Center of Excellence established to advance state-of-the-art electronics and to increase productivity in electronics manufacturing. The EMPF works with industry, academia, and government to identify, develop, transfer, and implement innovative electronics manufacturing technologies, processes, and practices. The EMPF conducts applied research, development, and proof-of-concept electronics manufacturing and design technologies, processes, and practices. It also seeks to improve education and training curricula, instruction, and necessary delivery methods. In addition, the EMPF is striving to identify, implement, and promote new electronics manufacturing technologies, processes, materials, and practices that will eliminate or reduce damage to the environment.

#### **National Center for Excellence in Metalworking Technology** (814) 269-2420

The National Center for Excellence in Metalworking Technology (NCEMT) is located in Johnstown, Pennsylvania and is operated by Concurrent Technologies Corporation (CTC), a subsidiary of the University of Pittsburgh Trust. In support of the NCEMT mission, CTC's primary focus includes working with government and industry to develop improved manufacturing technologies including advanced methods, materials, and processes, and transfer-

ring those technologies into industrial applications. CTC maintains capabilities in discrete part design, computerized process analysis and modeling, environmentally compliant manufacturing processes, and the application of advanced information science technologies to product and process integration.

#### **Center of Excellence for Composites Manufacturing Technology** (414) 947-8900

The Center of Excellence for Composites Manufacturing Technology (CECMT), a national resource, is located in Kenosha, Wisconsin. Established as a cooperative effort between government and industry to develop and disseminate this technology, CECMT ensures that robust processes and products using new composites are available to manufacturers. CECMT is operated by the Great Lakes Composites Consortium. It represents a collaborative approach to provide effective advanced composites technology that can be introduced into industrial processes in a timely manner. Fostering manufacturing capabilities for composites manufacturing will enable the U.S. to achieve worldwide prominence in this critical technology.

#### **Navy Joining Center** (614) 486-9423

The Navy Joining Center (NJC) is a Center of Excellence established to provide a national resource for the development of materials joining expertise, deployment of emerging manufacturing technologies, and dissemination of information to Navy contractors, subcontractors, Navy activities, and U.S. industry.

The NJC is located in Columbus, Ohio, and is operated by Edison Welding Institute (EWI), the nation's largest industrial consortium dedicated to materials joining. The NJC combines these resources with an assortment of facilities and demonstrated capabilities from a team of industrial and academic partners. NJC technical activities are divided into three categories - Technology Development, Technology Deployment, and Technology Transfer. Technology Development maintains a goal to complete development quickly to initiate deployment activities in a timely manner. Technology Deployment includes projects for rapid deployment teaming and commercialization of specific technologies. The Technology Transfer department works to disseminate pertinent information on past and current joining technologies both at and above the shop floor.



## APPENDIX E

### *NEW BEST MANUFACTURING PRACTICES PROGRAM TEMPLATES*

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Since 1985, the BMP Program has applied the templates philosophy with well-documented benefits. Aside from the value of the templates, the templates methodology has proven successful in presenting and organizing technical information. Therefore, the BMP program is continuing this existing "knowledge" base by developing 17 new templates that complement the existing DoD 4245.7-M or Transition from Design to Production templates.

The development of these new templates was based in part on Defense Science Board studies that have identified new technologies and processes that have proven successful in the last few years. Increased benefits could be realized if these activities were made subsets of the existing, compatible templates.

Also, the BMP Survey teams have become experienced in classifying Best Practices and in technology transfer.

The Survey team members, experts in each of their individual fields, determined that data collected, while related to one or more template areas, was not entirely applicable. Therefore, if additional categories were available for Best Practices "mapping," technology transfer would be enhanced.

Finally, users of the Technical Risk Identification and Mitigation System (TRIMS) found that the program performed extremely well in tracking most key program documentation. However, additional categories – or templates – would allow the system to track all key documentation.

Based on the above identified areas, a core group of activities was identified and added to the "templates baseline." In addition, TRIMS was modified to allow individual users to add an unlimited number of user-specific categories, templates, and knowledge-based questions.

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# APPENDIX F

## COMPLETED SURVEYS

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BMP surveys have been conducted at the companies listed below. Copies of older survey reports may be obtained through DTIC or by accessing the BMPNET. Requests for copies of recent survey reports or inquiries regarding the BMPNET may be directed to:

Best Manufacturing Practices Program  
4321 Hartwick Rd.  
Suite 308  
College Park, MD 20740  
Attn: Mr. Ernie Renner, Director  
Telephone: 1-800-789-4267  
FAX: (301) 403-8180

### COMPANIES SURVEYED

Litton  
Guidance & Control Systems Division  
Woodland Hills, CA  
October 1985 and February 1991

Texas Instruments  
Defense Systems & Electronics Group  
Lewisville, TX  
May 1986 and November 1991

Harris Corporation  
Government Support Systems Division  
Syosset, NY  
September 1986

Control Data Corporation  
Government Systems Division  
(Computing Devices International)  
Minneapolis, MN  
December 1986 and October 1992

ITT  
Avionics Division  
Clifton, NJ  
September 1987

UNISYS  
Computer Systems Division  
(Paramax)  
St. Paul, MN  
November 1987

Honeywell, Incorporated  
Undersea Systems Division  
(Alliant Tech Systems, Inc.)  
Hopkins, MN  
January 1986

General Dynamics  
Pomona Division  
Pomona, CA  
August 1986

IBM Corporation  
Federal Systems Division  
Owego, NY  
October 1986

Hughes Aircraft Company  
Radar Systems Group  
Los Angeles, CA  
January 1987

Rockwell International Corporation  
Collins Defense Communications  
Cedar Rapids, IA  
October 1987

Motorola  
Government Electronics Group  
Scottsdale, AZ  
March 1988

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General Dynamics  
Fort Worth Division  
Fort Worth, TX  
May 1988

Hughes Aircraft Company  
Missile Systems Group  
Tucson, AZ  
August 1988

Litton  
Data Systems Division  
Van Nuys, CA  
October 1988

McDonnell-Douglas Corporation  
McDonnell Aircraft Company  
St. Louis, MO  
January 1989

Litton  
Applied Technology Division  
San Jose, CA  
April 1989

Standard Industries  
LaMirada, CA  
June 1989

Teledyne Industries Incorporated  
Electronics Division  
Newbury Park, CA  
July 1989

Lockheed Corporation  
Missile Systems Division  
Sunnyvale, CA  
August 1989

General Electric  
Naval & Drive Turbine Systems  
Fitchburg, MA  
October 1989

TRICOR Systems, Incorporated  
Elgin, IL  
November 1989

TRW  
Military Electronics and Avionics Division  
San Diego, CA  
March 1990

Texas Instruments  
Defense Systems & Electronics Group  
Dallas, TX  
June 1988

Bell Helicopter  
Textron, Inc.  
Fort Worth, TX  
October 1988

GTE  
C<sup>3</sup> Systems Sector  
Needham Heights, MA  
November 1988

Northrop Corporation  
Aircraft Division  
Hawthorne, CA  
March 1989

Litton  
Amecom Division  
College Park, MD  
June 1989

Engineered Circuit Research, Incorporated  
Milpitas, CA  
July 1989

Lockheed Aeronautical Systems Company  
Marietta, GA  
August 1989

Westinghouse  
Electronic Systems Group  
Baltimore, MD  
September 1989

Rockwell International Corporation  
Autonetics Electronics Systems  
Anaheim, CA  
November 1989

Hughes Aircraft Company  
Ground Systems Group  
Fullerton, CA  
January 1990

MechTronics of Arizona, Inc.  
Phoenix, AZ  
April 1990

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Boeing Aerospace & Electronics  
Corinth, TX  
May 1990

Textron Lycoming  
Stratford, CT  
November 1990

Naval Avionics Center  
Indianapolis, IN  
June 1991

Kurt Manufacturing Co.  
Minneapolis, MN  
July 1991

Raytheon Missile Systems Division  
Andover, MA  
August 1991

Tandem Computers  
Cupertino, CA  
January 1992

Conax Florida Corporation  
St. Petersburg, FL  
May 1992

Hewlett-Packard  
Palo Alto Fabrication Center  
Palo Alto, CA  
June 1992

Digital Equipment Company  
Enclosures Business  
Westfield, MA and  
Maynard, MA  
August 1992

NASA Marshall Space Flight Center  
Huntsville, AL  
January 1993

Department of Energy-  
Oak Ridge Facilities  
Operated by Martin Marietta Energy Systems, Inc.  
Oak Ridge, TN  
March 1993

Technology Matrix Consortium  
Traverse City, MI  
August 1990

Norden Systems, Inc.  
Norwalk, CT  
May 1991

United Electric Controls  
Watertown, MA  
June 1991

MagneTek Defense Systems  
Anaheim, CA  
August 1991

AT&T Federal Systems Advanced  
Technologies and AT&T Bell Laboratories  
Greensboro, NC and Whippany, NJ  
September 1991

Charleston Naval Shipyard  
Charleston, SC  
April 1992

Texas Instruments  
Semiconductor Group  
Military Products  
Midland, TX  
June 1992

Watervliet U.S. Army Arsenal  
Watervliet, NY  
July 1992

Naval Aviation Depot  
Naval Air Station  
Pensacola, FL  
November 1992

Naval Aviation Depot  
Naval Air Station  
Jacksonville, FL  
March 1993

McDonnell Douglas Aerospace  
Huntington Beach, CA  
April 1993

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Crane Division  
Naval Surface Warfare Center  
Crane, IN and Louisville, KY  
May 1993

R. J. Reynolds Tobacco Company  
Winston-Salem, NC  
July 1993

Hamilton Standard  
Electronic Manufacturing Facility  
Farmington, CT  
October 1993

Harris Semiconductor  
Melbourne, FL  
January 1994

Naval Undersea Warfare Center  
(NUWC) Division Keyport  
Keyport, WA  
May 1994

Kaiser Electronics  
San Jose, CA  
July 1994

U.S. Army  
Combat Systems Test Activity  
Aberdeen, MD  
August 1994

Philadelphia Naval Shipyard  
Philadelphia, PA  
June 1993

Crystal Gateway Marriott Hotel  
Arlington, VA  
August 1993

Alpha Industries, Inc  
Methuen, MA  
November 1993

United Defense, L.P.  
Ground Systems Division  
San Jose, CA  
March 1994

Mason & Hanger  
Silas Mason Co., Inc.  
Middletown, IA  
July 1994

Stafford County Public Schools  
Stafford County, VA  
August 1994